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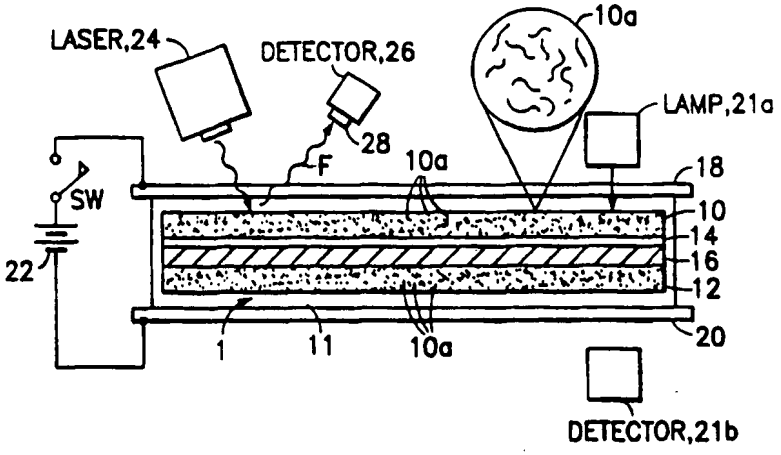
(54) Title: FIELD ACTIVATED SECURITY THREAD INCLUDING POLYMER DISPERSED LIQUID CRYSTAL



(57) Abstract

In a first aspect of this invention there is provided a security thread (1) which has an electrically actuated optical switch having a layer of polymer dispersed within a liquid crystal (10 and 12). The liquid crystal material has a visual characteristic that is switched between two states as a function of the presence or absence of an electric field. A second aspect of this invention provides a document or currency that has a paper matrix (11) including such a security thread. A third aspect of the invention provides a device for verifying the authenticity of a document or currency including the security thread. The device includes a first and second electrode (18 and 20), at least one of which is transparent. These electrodes function to create the electric field which activates the liquid crystal material.

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FIELD ACTIVATED SECURITY THREAD INCLUDING POLYMER DISPERSED LIQUID CRYSTAL

FIELD OF THE INVENTION:

This invention relates generally to document and currency authentication and, in particular, to security threads used in documents and currency.

BACKGROUND OF THE INVENTION:

In a publication entitled "Preparation and characterization of polymer dispersed liquid crystal films using photosensitive polymers", Die Angewandte Mackromolekulare Chemie 231 (1995) 109-121 (Nr. 4051), J.-H. Liu, M.-Z. Chen and Y.-F. Wang report on the preparation of polymer dispersed liquid crystal (PDLC) films using a photosensitive technique.

As is reported by these authors, a light scattering state in an a.c. electric field off state depends on optical heterogeneities such as a spatial distortion of nematic directions and/or mismatching in refractive indices of the compounds. The light scattering and light switching properties of the composite films are decisively influenced by the phase separation structure of the composite films. The size of a liquid crystal domain (channel) can be controlled on the basis of the solvent evaporation rate or the curing rate during the separation of the composite film.

The authors employed commercial liquid crystals ZLI-2444, 2452, 2459, and BDH-E7 without further treatment. For the

polymer matrix the authors used hydrophilic monomers of 2-hydroxythyl methacrylate (HEMA) and acrylic acid (Aa), hydrophobic monomers of methyl methacrylate (MMA) and styrene (St) that were purified by distillation in vacuo under nitrogen. 2-Methoxy-2phenylacetophenome (benzoin methyl ether, BME) was used without purification. The hydrophilic monomers were found to be suitable for the PDLC system. UV radiation was employed to photopolymerize the mixture, and it was found that sufficient UV irradiation was needed to complete the phase separation of the liquid crystals in the polymer matrix.

It is also known in the art to include isotropic dyes in an epoxy resin and liquid crystal when making optical shutters. The dye concentration can be adjusted to maximize the per cent transmission through the film between the on and off states. High contrast, colored displays have been made using an isotropic dye containing PDLC films and complementary colored backgrounds. Reference in this regard can be made to a publication entitled "Polymer Dispersed Liquid Crystals Incorporating Isotropic Dyes", SPIE Proceedings, 1080 (1989), J.L. West et al., and to a publication entitled "Characterization of polymer dispersed liquid-crystal shutters by ultraviolet/visible and Infrared absorption spectroscopy", J. Appl. Phys. 70(7), 1 October 1991, pgs. 3785-3790, J.L. West et al.

In U.S. Patent No. 5,448,582, issued September 5, 1995, entitled "Optical Sources Having a Strongly Scattering Gain Medium Providing Laser-Like Action", the inventor disclosed a multi-phase gain medium including an emission phase (such as dye molecules) and a scattering phase (such as TiO_2). A third, matrix phase may also be provided in some embodiments. Suitable materials for the matrix phase include solvents and polymers. The material is shown to provide a laser-like spectral linewidth collapse above a

certain pump pulse energy. Figs. 9a and 9b illustrate a display system embodiment having, in one embodiment, a liquid crystal display (LCD) array that is positioned adjacent to a surface of a pixel plane comprised of pixels or sub-pixels of the inventive gain medium. The LCD array is arranged so as to be selectively energized for passing the emission from the pixels through to an observer. The pixels operate so as to be substantially non-saturable and to output electromagnetic radiation within a narrow band of wavelengths.

It is well known in the art to use security threads in paper to hinder a non-authorized production of the paper or to authenticate already manufactured paper and/or a document or currency printed on the paper. Reference in this regard can be had to the following U.S. Patents: 5,486,022, "Security Threads Having At Least Two Security Detection Features and Security Papers Employing Same, by T.T. Crane; 4,534,398, "Security Paper", by T.T. Crane; and 4,437,935, "Method and Apparatus for Providing Security Features in Paper", by F.G. Crane, Jr.

OBJECTS OF THE INVENTION:

It is an object of this invention to provide an improved security thread for inclusion within documents and currency.

It is another object of this invention to provide an improved machine-readable security thread for inclusion within documents and currency.

It is a further object of this invention to provide an improved security thread having a polymer dispersed liquid crystal material layer that is responsive to an applied electric field for varying a visual characteristic of the

security thread.

It is another object of this invention to provide a security thread that includes a polymer dispersed liquid crystal material layer that includes at least one orientable dye, such as a dichroic or an isotropic dye, wherein the security thread is capable of laser-like action when excited by a source, and wherein the laser-like action can be switched on and off by switching an electric field on or off.

It is one further object of this invention to provide a paper that includes machine-readable security threads having a polymer dispersed liquid crystal material layer that includes at least one orientable dye, such as a dichroic or an isotropic dye, the security thread being responsive to an applied electric field for varying a visual characteristic of the security threads.

It is one further object of this invention to provide an improved security thread that includes at least one polymer dispersed liquid crystal film in combination with a non-saturable gain medium comprised of an optical emission phase, wherein dispersed liquid crystal domains function as an optical scattering phase.

SUMMARY OF THE INVENTION

The foregoing and other problems are overcome and the objects of the invention are realized by the embodiments of this invention.

In a first aspect this invention provides a security thread comprising an electrically actuated optical switch comprised of a layer of polymer dispersed liquid crystal material.

In a second aspect this invention provides a document or currency that comprises a paper matrix that includes at least one security thread, the at least one security thread being comprised of at least one layer of electrically actuated polymer dispersed liquid crystal material.

In a third aspect this invention provides a device for verifying an authenticity of a document or security of a type that includes at least one security thread. The device includes first and second electrodes and an excitation source coupled to the electrodes. The first and second electrodes are spaced apart for accommodating therebetween the document or currency, and at least one of the electrodes is transparent. The at least one security thread includes at least one layer of polymer dispersed liquid crystal material having a visual characteristic that is switched between two states as a function of a presence or absence of an electric field between the first and second electrodes.

In the various embodiments of this invention the polymer dispersed liquid crystal material layer may include at least one orientable dye, such as a dichroic or an isotropic dye, for enhancing the contrast between the on and off states of the PDLC material.

It is also within the scope of this invention to selectively pattern the polymer host or matrix that contains the liquid crystal, such as by selectively curing the material with UV radiation.

In accordance with a further embodiment of this invention a security thread has a polymer dispersed liquid crystal material layer that includes at least one orientable dye, such as a dichroic or an isotropic dye, wherein the security thread is capable of laser-like action when

excited by a source, and wherein the laser-like action can be switched on and off by switching an electric field on or off.

In a further embodiment of this invention there is disclosed a security thread that includes a polymer dispersed liquid crystal film that contains a material for generating a stimulated emission, in response to an optical pump, and scattering sites for scattering the stimulated emission. In this embodiment the liquid crystal domains function as the scattering sites, either alone or in combination with additional scattering sites. When the security thread is placed between first and second electrodes for establishing an electric field through the security thread, a spectrally and temporally collapsed laser-like emission can be turned on or off by the presence or absence, respectively, of an electric field between the associated pair of electrodes. The material for generating a stimulated emission can be comprised of, by example, dye molecules, semiconductor nanocrystals, or a polymer. The additional scattering sites may be, by example, particles of TiO_2 or alumina.

BRIEF DESCRIPTION OF THE DRAWINGS

The above set forth and other features of the invention are made more apparent in the ensuing Detailed Description of the Invention when read in conjunction with the attached Drawings, wherein:

Figs. 1A and 1B are each a cross-sectional view, not to scale, showing a security thread and the operation of PDLC domains without and with, respectively, an applied electric field;

Figs. 2A and 2B are each a top view of the security thread

of Figs. 1A and 1B, and illustrate a visual appearance of the security thread for a field off and a field on case, respectively;

Fig. 2C is a top view of a security thread having patterned PDLC material;

Fig. 2D is a top view of a security thread having bar code patterned PDLC material; and

Figs. 3A and 3B are each a cross-sectional view of a paper matrix, and illustrate the use of the security thread in a buried and in a windowed configuration, respectively, within the paper matrix.

DETAILED DESCRIPTION OF THE INVENTION

The disclosure of the above-referenced U.S. Patent No. 5,448,582, issued September 5, 1995, entitled "Optical Sources Having a Strongly Scattering Gain Medium Providing Laser-Like Action", by Nabil M. Lawandy is incorporated by reference herein in its entirety. Also incorporated by reference herein in its entirety is the disclosure of U.S. Patent No. 5,434,878, issued July 18, 1995, entitled "Optical Gain Medium Having Doped Nanocrystals of Semiconductors and also Optical Scatterers", by Nabil M. Lawandy.

Reference is made to Figs. 1A and 1B for illustrating an improved security thread 1 in accordance with this invention, as well as a device for activating the security thread 1. The security thread 1 is a multilayered structure that includes outer polymer dispersed liquid crystal (PDLC) layers 10 and 12, and inner layers comprised of a polyester or any suitable flexible thread-like material layer 14 and a thin metal layer 16, such as a layer of aluminum foil.

The layers 10 and 12 are comprised of a polymer matrix having an exemplary thickness of 5 micrometers that includes liquid crystal (LC) domains 10a distributed throughout. The layers 10 and 12 can be fabricated in accordance with, by example, the procedure disclosed in the above-mentioned journal article by J.-H. Liu et al.

In a presently preferred embodiment the LC material is added to a liquid polymer. The mixture is then used to coat on the layers 14 and 16, and is then dried or cured, depending on the liquid polymer. During the drying or curing process the LC domains 10a form within the surrounding polymer matrix, which is the desired result. When dried or cured the polymer matrix may also function as a protective coating for the layers 14 and 16. In a presently preferred embodiment of this invention the polymer matrix can be a transparent varnish or some other suitable coating material selected to adhere to the layers 14 and 16.

It is within the scope of this invention to selectively cure the security thread 1 with UV light or some other mechanism, such as a thermal process, so as to pattern one or both of the layers or films 10 and 12. By example, and referring to Fig. 2C, a striped pattern can be formed by applying UV light through a suitable mask. In this case the PDLC is formed only in the irradiated regions, resulting in a visually distinctive appearance when compared to a security thread wherein the entire layer 10 and 12 contains PDLC material.

The resulting security thread 1 is then placed into a matrix material, such as a paper matrix 11, and can then be printed on to provide the desired document or currency.

In order to activate the security thread 1 it is necessary

to apply an electric field. In this case the paper matrix 11 containing the security thread 1 is placed between opposed electrodes 18 and 20 that define a viewing area that encompasses all or a portion of the paper or document or currency within which the security thread 1 is disposed. The paper or document or currency may include a plurality of such security threads arranged in random or predetermined ways. At least one of the electrodes 18 and 20 is comprised of a transparent material such as indium-tin-oxide (ITO) or a thin, transparent film of a metal such as gold. The electrodes 18 and 20 may be provided on surfaces of transparent electrode substrates (such as glass), which are then arranged so as to place the electrodes 18 and 20 adjacent to the opposing major surfaces of the paper matrix 11 containing the security thread 1.

Coupled to the electrodes 18 and 20 is a suitable electrical excitation source 22 (shown as battery) that is connected to the electrode 18 through the switch (SW). A suitable potential for the source is in the range of 1V to 2V per micrometer. In Fig. 1A the switch is shown as being open, while in Fig. 1B the switch is shown as being closed. The switch being closed establishes an electric field through the intervening portion of the polymer matrix that contains the LC domains 10a. This causes the LC molecules within the LC domains 10a to align with the electrical field (as shown in the enlarged view of Fig. 1B) in a known manner. By contrast, the LC molecules in the LC domains 10a within a portion of the polymer matrix that is not subjected to an electric field remain in a random orientation, as shown in Fig. 1A.

When the LC molecules within a LC domain 10a are aligned, the composite index of refraction of the LC domain 10a more nearly matches that of the surrounding polymer matrix. As

a result, the optical absorption of the layers 10 and 12 is reduced, rendering the underlying layer or layers 14 and 16 visible. By contrast, the random orientation of the LC molecules provides a composite index of refraction which is not matched with the index of the surrounding polymer matrix. As a result, each such LC domain functions to absorb incident light and to prevent the light from reaching and/or reflecting from the underlying layer 14 or 16.

In this invention the properties of aligned and non-aligned LC molecules are employed to provide a security thread capable of assuming two distinct visual characteristics. Referring to Fig. 2A, in a first visual characteristic the LC molecules are not aligned, and the visual characteristic of the thread 1 may be that of an essentially opaque, featureless substrate. Referring to Fig. 2B, in a second visual characteristic the LC molecules are aligned by the electric field applied by transparent electrodes 18 and 20 in cooperation with excitation source 22, and the visual characteristic of the thread 1 is determined by the underlying layer or layers 14 and 16. That is, when the LC molecules of the domains 10a are aligned by the electric field caused by closing the switch (SW) of Fig. 1B, the domains 10a become substantially transparent. Assuming that one or both of the underlying layers 14 and 16 has a distinct visual characteristic, such as being colored, or patterned, and/or printed with an indicia (such as in Fig. 2B), then the security thread 1 takes on the visual characteristic of the one or more of the underlying layers 14 and 16.

Fig. 2C illustrates an embodiment of the above-mentioned selectively cured security thread 1. In this embodiment the security thread 1 contains regions 1a without PDLC, and regions 1b with PDLC. Only in the PDLC-containing regions

1b does the presence of the electric field result in the underlying layer becoming visible. The underlying layer may be colored and/or may include an indicia that becomes visible only in the regions 1b.

Fig. 2D illustrates a further embodiment of the invention, wherein all or a portion of the layers 10 and/or 12 are patterned in accordance with a bar code. For currency, the bar code can encode the denomination, serial number, and/or any other desired information. When the PDLC-containing regions are activated by the electric field, an underlying portion of the layer 14 or 16 is made visible, which may be colored black or some other color selected to provide a high contrast ratio.

It can be realized that the PDLC layers 10 and 12 function as an electrically actuated optical switch. When off, the PDLC layers prevent an observer from seeing the underlying layers 14 and 16, while when on these layers become visible.

In other embodiments of this invention one or more dyes or phosphors can be added to the polymer material that comprises the layers 10 and 12. By example, one or more isotropic or dichroic dyes can be added to the polymer matrix and liquid crystal material. After formation of the PDLC domains 10a, within the PDLC domains the dye or dyes become oriented or aligned with the bulk alignment of the LC molecules in the presence of the electric field. When so oriented the optical absorption of the dye or dyes is significantly reduced, resulting in a considerable contrast enhancement between the on and off states of the PDLC. Any of the dyes listed in the above-referenced West et al. publications can be employed for this purpose.

In a further embodiment of this invention the LC material

can be added to the polymeric material of the layer 14, and not to the layers 10 and 12. In this case the layers 10 and 12 may be eliminated, or can be retained for providing a protective coating for the layers 14 and 16.

Figs. 3A and 3B illustrate the use of the security thread 1 in a buried configuration (as in Figs. 1A and 1B), and in a windowed configuration, respectively, within the paper matrix 11.

It can be appreciated that the use of the security thread 1 provides both a public security feature and a machine readable security feature that can be readily verified using a low cost and simple reading apparatus. By example, in Figs. 1A and 1B there is shown a lamp 21a and an optical detector 21b which are arranged for sensing a difference in light transmission and/or reflection due to the activation of the PDLC material. For example, the metal layer 16, if used, may have openings or apertures that permit light from the lamp 21a to pass through to the photodetector 21b.

Furthermore, the use of the security thread 1 can be coupled with additional security features. By example, and referring again to Figs. 2B and 2C, the foil layer 16 could be printed with a holographic pattern that is only visible when an electric field of a suitable magnitude is applied across the paper matrix 11. In this case a document or currency containing the security thread 1 would be verified as being authentic only when an applied electric field renders an expected holographic pattern visible to an observer.

It is also within the scope of this invention to elicit a laser-like emission from the security thread 1 by modifying one or both of the layers 10 and 12 during fabrication to include a gain medium of a type disclosed in the above-

referenced U.S. Patent No. 5,448,582. By example, the layers 10 and/or 12 include dye molecules and may optionally contain scattering particles or sites. The dye molecules are selected to provide a desired color or emission wavelength. An exemplary dye molecule concentration is in the range of about 5 millimoles to about 10 millimoles. The scattering particles, which may be TiO_2 or alumina, are optionally employed to provide some degree of scattering, but not an amount sufficient to provide a laser-like emission from the layers 10 and/or 12.

When the switch of Fig. 1B is closed it establishes the electric field through the intervening portion of the layers 10 and 12. This causes the LC molecules within the LC domains 10a to align with the electrical field in a known manner. As was noted above, when the LC molecules within a LC domain 10a are aligned, the composite index of refraction of the LC domain 10a more nearly matches that of the surrounding polymer matrix. In contrast, the random orientation of the LC molecules provides a composite index of refraction which is not matched with the index of the surrounding polymer matrix. As a result, each such LC domain functions as a scattering site which, in combination with the dye molecules, provides a laser-like emission from the layers 10 and or 12 when excited by an external pump source, such as a frequency double Nd:YAG laser (shown as 24 in Figs. 1A and 1B). The presence of the laser like emission having a specified narrow bandwidth can be detected by a suitable optical detector 26 that is fitted with a narrow passband filter (F) 28.

The additional scattering sites may be provided so as to "bias" the material of the layers 10 and 12 below the point required to support the laser-like emission. In this case the additional scattering provided by the LC domains 10a having LC molecules in the random orientation as in Fig. 1A

is sufficient to exceed the threshold required to support the laser-like emission, whereas the reduction in scattering caused by the aligned LC domains of Fig. 1B is not sufficient to support the laser-like emission.

In this embodiment of the invention these properties of aligned and non-aligned LC molecules are employed to provide a high brightness and high contrast security thread. It can thus be appreciated that the teaching of this invention provides an electrically actuated lasing security thread having a large contrast between the on and off states.

In a further embodiment of this invention the dye molecules may be replaced by semiconductor nanocrystals selected for their emission wavelength(s) (e.g., GaN for blue, ZnSe for green, CdSe for red). In this case the semiconductor nanocrystals may also function as scattering sites for the stimulated emission in combination with the LC domains 10a. In a still further embodiment of this invention the polymer matrix of the layers 10 and 12 may itself may provide the stimulated emission, such as a polymer matrix comprised of, by example, PPV, MEHPPV, BuEH-PPV, BEH-PPV, HEH-PF, or CN-PPP.

In the various embodiments of the invention described above the PDLC layers 10 and 12 may have a thickness of, by example, 5-10 micrometers. An electric potential in the range of approximately 15-50 volts is sufficient to align the LC molecules within the LC domains 10a.

Although described above in the context of specific materials, thicknesses, potentials, dimensions and the like, it should be appreciated that the teaching of this invention is not intended to be limited to only these disclosed exemplary embodiments and values. Neither is the

teaching of this invention intended to be limited to only the specific electric field generating technique and apparatus described above.

As such, while the invention has been particularly shown and described with respect to preferred embodiments thereof, it will be understood by those skilled in the art that changes in form and details may be made therein without departing from the scope and spirit of the invention.

CLAIMS

What is claimed is:

1. A security thread, comprising an electrically actuated optical switch comprised of a layer of polymer dispersed liquid crystal material.

2. A document or currency, comprising a paper matrix that includes at least one security thread, said at least one security thread being comprised of at least one layer of electrically actuated polymer dispersed liquid crystal material.

3. A device for verifying an authenticity of a document or security of a type that includes at least one security thread, comprising first and second electrodes and an excitation source coupled to said electrodes, said first and second electrodes being spaced apart for accommodating therebetween said document or currency, at least one of said electrodes being transparent, said at least one security thread being comprised of at least one layer of polymer dispersed liquid crystal material having a visual characteristic that is switched between two states as a function of a presence or absence of an electric field between said first and second electrodes.

4. A security thread, comprising an electrically actuated optical switch comprised of a layer of polymer dispersed liquid crystal material that includes at least one orientable dye for enhancing a contrast between on and off states of the polymer dispersed liquid crystal material.

5. A security thread, comprising at least one layer that contains an optical gain medium and an electrically

actuated optical switch comprised of polymer dispersed liquid crystal material.

6. A security thread, comprising:

at least one layer comprised of a polymer dispersed liquid crystal material that contains a material for generating a stimulated emission, in response to an optical pump, and electrically activated scattering sites for scattering the stimulated emission.

7. A security thread, comprising an electrically actuated optical switch comprised of a patterned layer of polymer dispersed liquid crystal material.

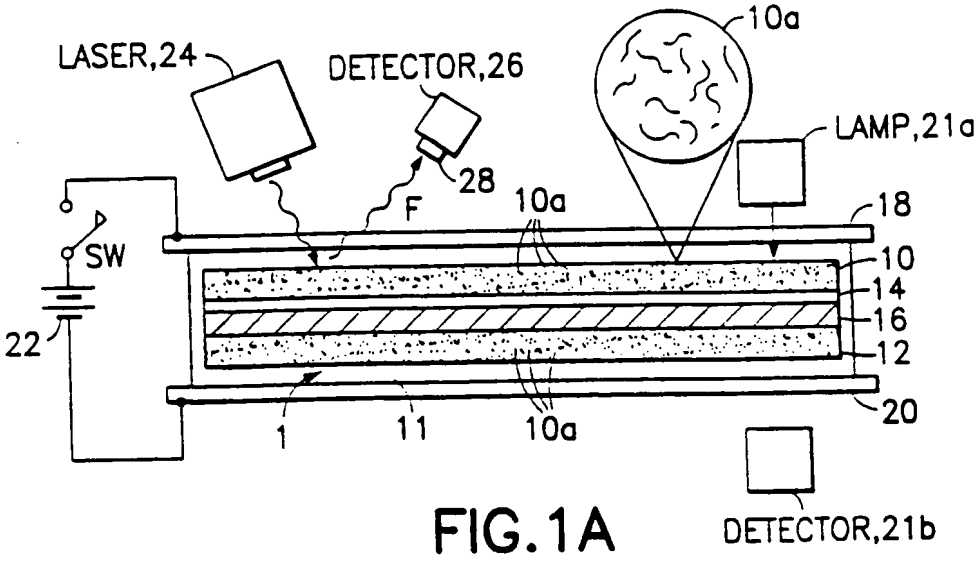
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FIG.1A

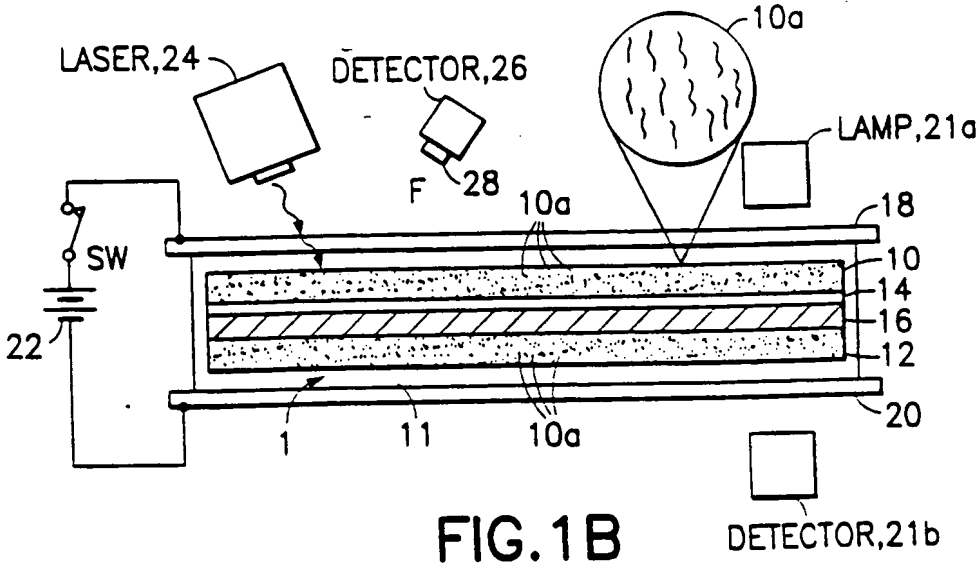
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FIG.1B

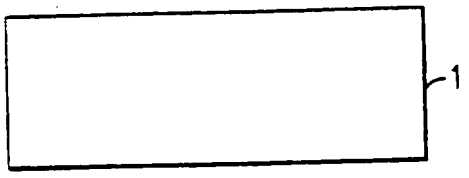

FIG.2A

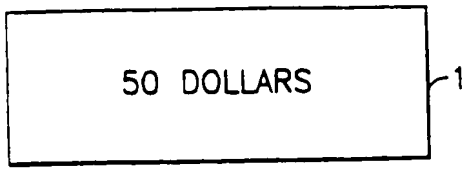

FIG.2B

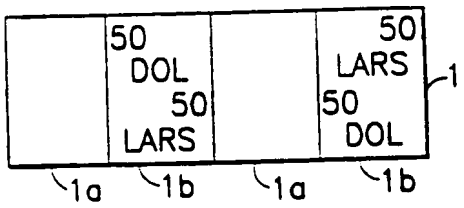

FIG.2C

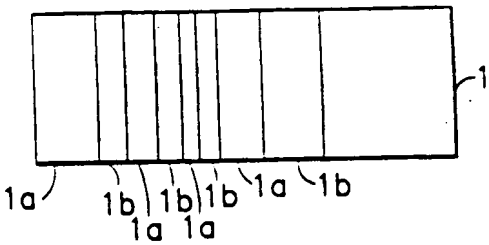

FIG.2D

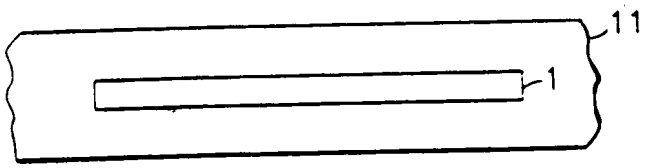

FIG.3A

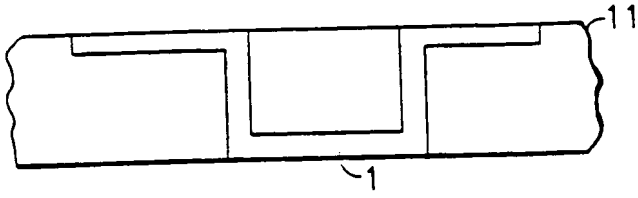

FIG.3B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US98/02316

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G06K 19/06
US CL :235/492

According to International Patent Classification (IPC) or to both national classification and IPC.

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 235/492, 493, 379, 449; 162/140; 283/82, 83, 84, 85

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
search terms: currency, code, security, thread, security thread, liquid crystal, polymer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,652,015 A (CRANE) 24 March 1987 (24/03/87),column 2 line 63 - column 3 line10.	1-7
Y	US 4,761,205 A (CRANE) 02 August 1988 (02/08/88), column 2 line 64 - column 3 line 10.	1-7
Y	US 4,702,558 A (COLES ET AL) 27 October 1987 (27/10/87), column 3 lines 29-41.	1-7

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 20 APRIL 1998	Date of mailing of the international search report 07 MAY 1998
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